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COMMUNICATION SYSTEM, RECEIVER APPARATUS AND COMMUNICATION METHOD

Inventor; and Inventor/Applicant (for US only):	Wataru Matsumoto Mitsubishi Electric Corp. 2-2-3 Marunouchi, Chiyoda-ku, Tokyo
Applicant (for all designated states other than US):	Mitsubishi Electric Corp.

2-2-3 Marunouchi, Chiyoda-ku,
Tokyo

Agent: Hiroaki Sakai
Tokyo Club Bldg., 3-2-6
Kasumigaseki, Chiyoda-ku, Tokyo
100-0013 Japan

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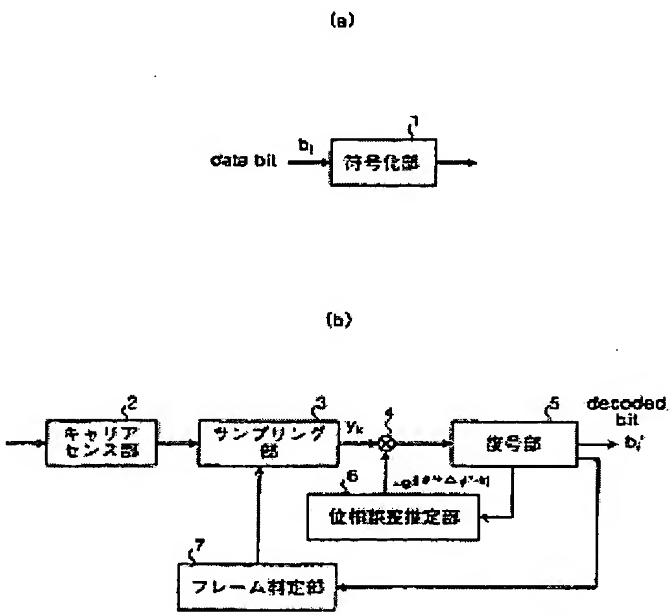
Abstract



1...ENCODING PART
2...CARRIER SENSING PART
3...SAMPLING PART
5...DECODING PART
6...PHASE ERROR ESTIMATING PART
7...FRAME DECIDING PART

(57) Abstract: In a receiver apparatus, a decoding part (5) executes a single LDPC decoding of a received signal by use of "sum-product algorithm" at a plurality of sample points that are candidates of a sample starting point; a phase error estimating part (6) uses a soft-decision information outputted during the decoding to execute a phase error estimation based on MMSE; a multiplier (4) corrects, based on the result of the estimation, the received signal; and a frame deciding part (7) compares an average (A) of the absolute values of the latest logarithmic likelihood ratios with an average (B) of the absolute values of the immediately preceding logarithmic likelihood ratios to determine whether to terminate the correction processing, and if (B) is equal to or greater than (A), the frame deciding part (7) terminates the correction processing, and thereafter, uses, as the sample start point of the frame, a point corresponding to the maximum value of the averages of the absolute values of the logarithmic likelihood ratios at the candidates of the sample starting point.

Specification

Communication system, receiver apparatus and communication method

Technical field

The present invention pertains to a communication system that can perform synchronization control without using a preamble, user code, or other prescribed symbols. In particular, the present invention pertains to a communication system, receiver and communication method that allows synchronization control using an LDPC (Low-Density Parity-Check) encoded signal.

Prior art

In the following, synchronization control of the prior art will be explained. First, the method for establishing the synchronization method of the prior art will be explained. For example, on the transmitting side, phase inverted N signals (preambles) are transmitted (see the upper section and middle section of Figure 12). On the receiving side, phase inversion is detected in the preamble, a synchronization signal is output at this timing (see the lower section of Figure 12), and the data of the modulated data is demodulated. Usually, it is possible to establish correct synchronization even in a noisy communication line. Consequently, in many cases, said number N is set to 10 or more.

In the following, the user detection method of the prior art will be explained. Usually, on the receiving side, the user code that is transmitted after said preamble is used, and whether the receiving frame is a communication frame towards the device is checked (see Figure 13). In this case, on the receiving side, user detection is performed to check for agreement with the unique code assigned to the given device. Usually, in order to reduce the probability of accidental agreement with the code pattern by means of noise, etc., usually, at least 1 byte (8 bits) or more is assigned to the user code. Also, as far as the constitution of the communication frame is concerned, for example, various types of control codes are arranged on either side of said user code, followed by the data for the user (payload data) (See Figure 13.)

However, in the aforementioned conventional communication method, the preamble or user code is set in the communication frame to perform synchronization control. Consequently, the communication frame is redundant, which is undesirable.

The purpose of the present invention is to provide a communication system, receiver and communication method that can perform correct synchronization control without using a preamble or user code.

Disclosure of the invention

The present invention provides a communication system characterized by the fact that it has the following parts: a transmitter that executes the LDPC encoding process, a decoding means that executes LDPC decoding once (iteration: 1) with the "sum-product algorithm" with

respect to the received signal at plural sample points as candidates of the sample starting point, a phase error estimating means that uses the soft judgment information output during the process of said decoding to estimate the phase error using the minimum mean square error method (MMSE), and a correcting means that corrects the received signal on the basis of said estimation result.

The present invention provides a communication system characterized by the following facts: said receiver also has a frame synchronization control means that performs the following operation: judgment is made on whether said correction process is finished by comparing the mean value of the absolute values of the latest logarithmic likelihood ratios (A) with the mean value of the absolute values of the immediately preceding logarithmic likelihood ratios (B); if the judgment result is B < A, the received signal after correction is used to execute LDPC decoding and the correction process again; on the other hand, if the result of execution of repeated decoding using the corrected received signal is B ≥ A, the correction process is finished; then, the maximum value is selected from the mean values of the absolute values of the logarithmic likelihood ratios corresponding to the candidates for said sample starting point; and the point corresponding to the maximum value is taken as the sample starting point of the frame; said decoding means performs LDPC decoding repeatedly until a prescribed number of iterations is reached or when there is no error for the selected frame.

Also, the present invention provides a communication system characterized by the fact that in this communication system, said receiver determines the candidates for the sample starting point by means of carrier sensing.

In addition, the present invention provides a type of receiver characterized by the fact that it has the following parts: a decoding means that executes LDPC decoding once (iteration: 1) with "sum-product algorithm" with respect to the received signal at plural sample points as candidates for the sample starting point, a phase error estimating means that uses the soft judgment information output during the process of said decoding to execute phase error estimation using the minimum mean square error method (MMSE), and a correcting means that corrects the received signal on the basis of said estimation result.

The present invention provides a receiver characterized by the fact that it also has a frame synchronization control means that performs the following operation: judgment is made on whether said correction process is finished by comparing the mean value of the absolute values of the latest logarithmic likelihood ratios (A) with the mean value of the absolute values of the immediately preceding logarithmic likelihood ratios (B); if the judgment result is B < A, the received signal after correction is used to execute LDPC decoding and the correction process again; on the other hand, if the result of execution of repeated decoding using the corrected received signal is B ≥ A, the correction process is finished; then, the maximum value is selected

from the mean values of the absolute values of the logarithmic likelihood ratios corresponding to the candidates for said sample starting point; and the point corresponding to the maximum value is taken as the sample starting point of the frame; said decoding means performs LDPC decoding repeatedly until a prescribed number of iterations is reached or when there is no error for the selected frame.

Also, the present invention provides a receiver characterized by the fact that in this receiver, the candidates for the sample starting point are determined by means of carrier sense.

Moreover, the present invention provides a communication method characterized by the fact that it is comprised of the following steps: a first decoding step in which LDPC decoding is executed once (iteration: 1) with the "sum-product algorithm" with respect to the received signal at a prescribed sample point, a phase error estimating step in which the soft judgment information output during the process of said decoding is used to execute phase error estimation using minimum mean square error method (MMSE), a correction step in which the recorded signal is corrected on the basis of said estimation result, a judgment step in which judgment is made on whether said correction process is finished by comparing the mean value of the absolute values of the latest logarithmic likelihood ratios (A) with the mean value of the absolute values of the immediately preceding logarithmic likelihood ratios (B), and a second decoding step in which the following operation is performed: if the judgment result is $B < A$, the received signal after correction is used to execute LDPC decoding and the correction process again; on the other hand, if the result of execution of repeated decoding using the corrected received signal is $B \geq A$, the correction process is finished, and said LDPC decoding is executed repeatedly until the a prescribed number of iterations is reached or when there is no error.

In addition, the present invention provides a communication method characterized by the fact that it is comprised of the following steps of operation: a first decoding step in which LDPC decoding is executed once (iteration: 1) with the "sum-product algorithm" with respect to the received signal at plural sample points as candidates for the sample starting point, a phase error estimating step in which the soft judgment information output during the process of said decoding is used to execute phase error estimation using the minimum mean square error method (MMSE), a first correction step in which the received signal is corrected on the basis of said estimation result, a judgment step in which judgment is made on whether said correction process is finished by comparing the mean value of the absolute values of the latest logarithmic likelihood ratios (A) with the mean value of the absolute values of the immediately preceding logarithmic likelihood ratios (B), a second decoding step in which the operation is performed such that if the judgment result is $B < A$, the received signal after correction is used to execute the LDPC decoding and correction process again, a frame synchronization step in which the operation is performed such that if the result of execution of repeated decoding using the

corrected received signal is $B \geq A$, the correction process is finished, the maximum value among the mean values of the logarithmic likelihood ratios corresponding to said candidates for the sample starting point is selected, and the point corresponding to said maximum value is taken as the sample starting point of the frame, and a second decoding step in which the operation is performed such that for the selected frame, said LDPC decoding is executed repeatedly until a prescribed number of iterations is reached or when there is no error.

Also, the present invention provides a communication method characterized by the fact that the candidates for the sample starting point are determined by means of carrier sensing.

Brief description of the figures

Figure 1 is a diagram illustrating the constitution of the communication system of the present invention. Figure 2 is a diagram illustrating the frame structure. Figure 3 is a diagram illustrating the parameters pertaining to communication between communication devices. Figure 4 is a diagram illustrating the parameters pertaining to communication between communication devices. Figure 5 is a diagram illustrating the mean value of absolute values of LLR at the various sample points. Figure 6 is a diagram illustrating the probability of the frame error rate. Figure 7 is a diagram illustrating the regression straight line of $\theta' + \Delta\varphi'$. Figure 8 is a diagram illustrating the probability of the frame error. Figure 9 is a diagram illustrating the BER characteristics. Figure 10 is a diagram illustrating the probability density distribution of the estimated value of the timing offset. Figure 11 is a diagram illustrating the probability density distribution of the estimated value of the frequency offset. Figure 12 is a diagram illustrating the synchronization control method of the prior art. Figure 13 is a diagram illustrating the user detection method of the prior art.

Preferred embodiment of the invention

In the following, a detailed explanation will be presented of a preferred embodiment of communication system, receiver and communication method with reference to the attached figures. However, the present invention is not limited to said embodiment.

Figure 1 illustrates the constitution of the communication system of the present invention. More specifically, (a) shows the constitution of the communication device on the transmitting side (transmitter), and (b) shows the communication device on the receiving side (receiver). In Figure 1, (1) represents the encoding part; (2) represents the carrier sense part; (3) represents the sampling part; (4) represents a multiplier; (5) represents a decoding part; (6) represents a phase error estimation part; and (7) represents a frame judgment part.

In the communication devices in said communication system, LDPC codes are used as error correction codes. Also, in the LDPC encoding/decoding processing, an AWGN (Additive White Gaussian Noise) communication line is assumed.

For example, if QPSK (Quadrature Phase Shift Keying) modulation with encoding rate of 0.5 is used, received signal y_k in the communication device on the receiving side can be represented by following Equation (1):

$$y_k = c_k + n_k = r_{2k-1} + j \quad \cdots \quad (1)$$

Also, said received signal y_k is a complex received signal at sample point k. Here, k = 1, 2, ... $L_c/2$; L_c represents the code length; c_k represents the encoding series of QPSK; and n_k represents the complex additive white Gaussian noise $2\delta_0^2$. Also, sample point k of the complex received signal contains 2 sample points on the real and imaginary axes. The spacing between the sample points on the time axis is Ts. That is, on the time axis, sample points on the real axis and imaginary axis take place alternately with spacing Ts.

Also, said encoded series c_k of QPSK is given by following Equation (2). Here, the received signals corresponding to u_{2k-1} and u_{2k} are r_{2k-1} and r_{2k}, respectively.

$$c_k = u_{2k-1} + j \cdot u_{2k} \quad \cdots \quad (2)$$

Also, a model of the received signal y_k can be formed using following Equation (3). Here, θ represents the timing offset, and Δ'φ represents the carrier frequency offset.

$$y_k = e^{j(\theta + \Delta\phi \cdot k)} c_k + n_k \quad \cdots \quad (3)$$

In the following, the basic operation of the frame synchronization control using the LDPC codes will be explained. Here, the LDPC encoded signal is decoded using the "sum-product algorithm", a conventional decoding method. Frame synchronization control is performed using the mean value of the absolute values of LLR (logarithmic likelihood ratio) output from said "sum-product algorithm". Also, the frame length is assumed to be equal to the encoded word length. Also, the receiver (the communication device on the receiving side) has a function for detecting the carrier power (carrier sense). With the carrier sense function, the starting position of the receiving frame is roughly estimated.

First, in the transmitter (the communication device on the transmitting side), the binary data is encoded using an LDPC encoder for generating encoded words b_i (i = 1, 2, ... L_c). Also, the encoded words are taken as those that have been mapped to the signal constellation points. Also, the real axis is u_{2k-1} {+1, -1}, and the imaginary axis is u_{2k} {+1, -1}.

The process pertaining to transmission and reception is applied to the block of the data bit $b_i \in \{1, 0\}$ with data length <0. Consequently, if the encoding rate is R ($0 \leq R \leq 1$), the code length L_c becomes $L_c = L_D/R$.

In the receiver, after carrier sense, by analyzing of consecutive ±M sample points, that is, by executing "sum-product algorithm" with consecutive ±M sample points, the frame synchronization is established. In the "sum-product algorithm", probability Pr $\{u_k=+1|r\}$ and probability Pr $\{u_k=-1|r\}$ obtained from block of the received symbol $r = [r_1, r_2, \ldots r_{LC}]$ are computed. More specifically, for example, pseudo-post LLR (logarithmic likelihood ratio) is computed using Equation (4) by means of the first cycle of repeated decoding.

$$L_u^1(u_i) \equiv \ln \frac{\Pr\{u_i = +1|r\}}{\Pr\{u_i = -1|r\}} \quad \cdots \quad (4)$$

According to Equation (5), the maximum value among the mean values of the absolute values of LLR at the ±M sample points is detected, and the point corresponding to the maximum value is taken as sample starting point g'. Figure 2 is a diagram illustrating the frame structure.

$$g' = \arg \max_{g \in [-M,M]} \frac{1}{L_c} \sum_{s=g}^{g+L_c-1} | L_u(u_s) | \quad \cdots \quad (5)$$

After the frame synchronization is established using said Equations (4) and (5), the receiver continues the decoding processing with "sum-product algorithm".

Then, using "irregular-LDPC code" with encoding rate = 0.5, it is checked whether the frame synchronization has been established. Figures 3 and 4 are diagrams illustrating the parameters pertaining to the communication between said communication devices. Figure 4 shows an example of un-sample [transliteration] (weight assignment) of the "irregular-LDPC code", where λ_x represents the proportion of the total weight contained in the column of weight x with respect to the overall weight of the checking matrix; ρ_x represents the proportion of the total weight contained in the row of weight x with respect to the overall weight of the checking matrix; and No. represents the number of columns or rows of weight x. Also, σ_{GA} represents the estimation threshold represented using the standard deviation of the communication line noise using Gaussian approximation method; SNR_{norm} (GA) is the difference from the Shannon limit represented in dB. Also, at an encoding rate of 0.5, the Shannon limit is taken as $\sigma = 0.9769$.

Figure 5 is a diagram illustrating the mean value of the absolute values of LLR at the various sample points given by Equation (5). The receiver detects the point with the maximum value among the mean values of the absolute values of LLR, so that it is possible to establish the frame synchronization correctly.

Also, in order to estimate the degradation in the performance that takes place due to an inappropriate sample point, the frame synchronization at different timing offset states is evaluated. Figure 6 is a diagram illustrating the probability of the frame error due to different timing offsets from 0° to 45°. The results indicate that for the receiver with the aforementioned frame synchronization control, when the timing offset is over 30°, it is difficult to recover the frame synchronization. That is, when the timing offset is over 30°, the frame error characteristics become worse.

The foregoing is an explanation of the basic operation of the frame synchronization control using LDPC code. In the following, with reference to Figure 1, a detailed explanation will be presented of the operation of the receiver in this embodiment in which frame synchronization control and decoding processing are performed while said timing offset and frequency offset are corrected. Also, the operation of the transmitter (the portion corresponding to encoding part (1)) is the same as was described above, so that it will not be explained in detail again.

More specifically, in this embodiment, when synchronization is not taken for the sample timing and the carrier frequency, the timing offset and frequency offset are estimated using the soft judgment bit output using the "sum-product algorithm". In this case, in the receiver, the minimum mean square error (MMSE) is used to execute the expanded "sum-product algorithm". This expanded "sum-product algorithm" is composed of the MMSE of the phase error estimation/correction process, frame synchronization process, and the conventional "sum-product algorithm" process.

(A) MMSE phase error estimation/correction process

First, in decoding part (5), the initial LLR message of the received signal is computed using the following Equation (6). In this case, the repetition counter in decoding part (5) is $l = 1$, and the maximum number of the repetitions is set at l_{max}.

$$L_u^0(u_i) \equiv \ln \frac{\Pr\{u_i = +1|r\}}{\Pr\{u_i = -1|r\}}$$

$$= \frac{1/\sqrt{2\pi\sigma_0^2}\exp\left(-(r_i-1)^2/2\sigma_0^2\right)}{1/\sqrt{2\pi\sigma_0^2}\exp\left(-(r_i+1)^2/2\sigma_0^2\right)} = \frac{2r_i}{\sigma_0^2} \quad \cdots (6)$$

Then, using the parity checkup matrix H, "sum-product algorithm" is executed once (iteration = 1).

Then, in decoding part (5), the pseudo LLR of encoded signal $\{u_k\}^{Lc}$ (where k = 1) after one repetition cycle is used to determine soft judgment bit u_k' using the following Equation (7). Here, $E\{\cdot\}$ represents the mean value.

$$
\begin{aligned}
u_k' &= E\{u_k\} \\
&= Pr\{u_k = +1\} \cdot 1 + Pr\{u_k = -1\} \cdot (-1) \\
&= \ln \frac{\exp(L_u^1(u_k))}{1+\exp(L_u^1(u_k))} + \frac{-1}{1+\exp(L_u^1(u_k))} \\
&= \tanh\left(\frac{L_u^1(u_k)}{2}\right)
\end{aligned}
\quad \cdots (7)
$$

Then, in phase error estimation part (6), by means of MMSE, that is, using following Equations (8) and (9), phase error (θ', Δφ') is determined.

$$
\theta' + \Delta\phi' \cdot k = \arg\min E\left\{\left|\tan^{-1}\frac{\mathrm{Im}[y_k / c_k']}{\mathrm{Re}[y_k / c_k']} - (\theta' + \Delta\phi' \cdot k)\right|^2\right\} \quad \cdots (8)
$$

$$
\begin{aligned}
E_p' &= \frac{1}{L_c/2}\sum_{k=1}^{L_c/2}\tan^{-1}\frac{\mathrm{Im}[y_k / c_k']}{\mathrm{Re}[y_k / c_k']} \\
\text{where} E_p(k) &= \tan^{-1}\frac{\mathrm{Im}[y_k / c_k']}{\mathrm{Re}[y_k / c_k']} \\
k' &= \frac{1}{L_c/2}\sum_{k=1}^{L_c/2} k \\
\Delta\phi' &= \frac{\sum k \cdot E_p(k) - (L_c/2)\cdot E_p' \cdot k'}{\sum k^2 - (L_c/2)\cdot(k')^2} \\
\theta' &= \frac{E_p \cdot \sum k^2 - k'\sum k\, E_p(k)}{\sum k^2 - (L_c/2)\cdot(k')^2}
\end{aligned}
\quad \cdots (9)
$$

Also, $c_k' = u_{2k-1}' + j\, u_{2k}'$.

Im represents the imaginary axis, Re represents the real axis, θ' represents the estimation sample error (timing offset), Δφ' represents the estimated clock error (frequency offset), and θ'+Δφ' can be considered a linear regression line. Figure 7 is a diagram illustrating the regression line of

$$\theta' + \Delta\phi'$$

Also E_p' represents the mean value of the soft judgment phase error.

Then, with multiplier (4), the soft judgment phase error of the received signal (timing offset, frequency offset) is corrected. That is, as shown in Equation (10), received signal y_k is multiplied by the above determined phase error to get corrected value y_k' of the received signal. As a result, Equation (11) is used to obtain the corrected received signal.

$$\begin{aligned} y_k' &= y_k \cdot e^{-j(\theta' + \Delta\phi' \cdot k)} \\ &= (r_{2k-1} + j \cdot r_{2k}) \cdot (\cos(\theta' + \Delta\phi' \cdot k) - j \cdot \sin(\theta' + \Delta\phi' \cdot k)) \end{aligned} \quad \cdots \text{(10)}$$

$$\begin{aligned} r_{2k-1}' &= \mathrm{Re}\{(r_{2k-1} + j \cdot r_{2k}) \cdot (\cos(\theta' + \Delta\phi' \cdot k) - j\sin(\theta' + \Delta\phi' \cdot k))\} \\ r_{2k}' &= \mathrm{Im}\{(r_{2k-1} + j \cdot r_{2k}) \cdot (\cos(\theta' + \Delta\phi' \cdot k) - j\sin(\theta' + \Delta\phi' \cdot k))\} \end{aligned} \quad \cdots \text{(11)}$$

Then, in decoding part (5), said corrected received signal is used to refresh LLR. The LLR message refreshed by correction is given by following Equation (12).

$$L_u^0(u_i) \equiv \ln \frac{\Pr\{u_i = +1 | r'\}}{\Pr\{u_i = -1 | r'\}} = \frac{2r_i'}{\sigma_0^2} \quad \cdots \text{(12)}$$

Then, frame judgment part (7) judges whether said correction process of the phase error has finished by comparing the latest LLR mean value m^l with the mean value of the immediately preceding LLR, m^{l-1}. For example, suppose the judgment result with frame judgment part (7) is $m^{l-1} < m^l$, decoding part (5), phase error estimation part (6) and multiplier (4) are used to perform the process after the "sum-product algorithm" again. Also, the mean value of LLR, m, is given by the following Equation (13).

$$m_u^l = \frac{1}{L_c} \sum_{i=1}^{L_c} | L_u^l(u_i) | \quad \cdots \text{(13)}$$

(B) Frame synchronization process

On the other hand, if the result of the judgment made by said frame judgment part (7) is $m^{l-1} \geq m^l$, in decoding part (5), following Equation (14) is executed for frame synchronization control. More specifically, the maximum value is detected from the mean values of the absolute values of LLR corresponding to the ±M sample points, that is, the 2M+1 candidates for the sample starting point, and the point corresponding to the maximum value is taken as sample starting point g' of the frame. The process up to this step is the process with "iteration = 1". Also, the 2M+1 candidates for the sample starting point are determined on the basis of the information from carrier sense part (2) that allows detection of the carrier power. With said carrier sense

function, it is possible to make a rough estimate of the starting position of the receiving frame (candidate for the sample starting point).

$$g' = \arg\max_{g\in[-M,M]} \frac{1}{L_c}\sum_{s=g}^{g+L_c-1} | L_u^1(u_s) | \cdots \quad (14)$$

(C) Conventional "sum-product algorithm" process

Then, in decoding part (5), for the frame selected in the process of (B), the conventional "sum-product algorithm" is carried out. That is, when the temporary hard judgment bits

$$(b_1', b_2', \cdots b_{Lc}') \text{ meet } (b_1', b_2', \cdots b_{Lc}') \times H = 0$$

the hard judgment bits are output, and "sum-product algorithm" is stopped. On the other hand, if $(b_1', b_2', \cdots b_{Lc}') \times H = 0$ is not established, and $l \leqq l_{max}$ count value (l) in decoding part (5) is incremented, and decoding is continued until one has $l = l_{max}$,

An explanation was presented above of the basic operation of the frame synchronization control using the LDPC code and the operation of the receiver in this embodiment with frame synchronization and decoding processing performed while said timing offset and frequency offset are corrected. The decoding characteristics of the receiver of this embodiment will be examined below..

Figure 8 is a diagram illustrating the probability of the frame error by means of different timing offsets from 0° to 45° when the receiver of this embodiment is used (when phase error correction is performed using MMSE). In the decoding method of this embodiment, even when the timing offset reaches 30°, it is still possible to detect the frame position correctly with SNR of about 2 dB.

Figure 9 is a diagram illustrating the BER characteristics. In the figure, "0°", "20°", "40°", "45°" represent the values of the timing offsets. On the other hand, the frequency offset is set at -0.0036° (-10 ppm) in all cases. For example, with $\Delta\varphi$ of -0.0036° (-10 ppm), when the number of repetitions is 100 cycles, and "20°" at the point with BER=10^{-4}, there is only a degradation of 0.3 dB as compared to "0°". In addition, even in the case of "40°", the degradation is only about 0.8 dB as compared with the case of "0°".

Figure 10 is a diagram illustrating the probability density distribution of the estimated values for the timing offset. Figure 11 is a diagram illustrating the probability density distribution for the estimated values of the frequency offset. From these figures, it can be seen that when the estimated values for the timing offset and the frequency offset exceed the estimation threshold using the Gaussian approximation method, the correction level rises as the ratio E_b/N_0 increases.

In this way, this embodiment has a constitution with a soft judgment phase correction function by means of MMSE in conventional decoding processing ("sum-product algorithm"). That is, the constitution is such that the frame synchronization control and decoding processing are performed while timing offset and frequency offset are corrected, without using a PLL. As a result, in the case of QPSK modulation, even when a timing offset of about 40° takes place, it is still possible to obtain good characteristics (decoding performance).

As explained above, according to the present invention, the constitution is such that there is a soft judgment phase error correction function by means of MMSE in conventional decoding processing ("sum-product algorithm"). As a result, even when a timing offset of about 40° takes place, it is still possible to obtain a communication system that can suppress degradation of the characteristics (decoding performance). This is one effect of the present invention.

Then, according to the present invention, a frame constitution without a preamble or user code is used in which frame synchronization control and decoding processing are performed while the timing offset and frequency offset are corrected without using a PLL. As a result, it is possible to prevent wasteful redundancy of the frame, and it can provide a communication system that allows correct detection of the frame position. This is another effect of the present invention.

Then, according to the present invention, the constitution is such that the 2M+1 candidates for the sample starting point are determined using the carrier sense function. With said carrier sense function, it is possible to obtain a communication system that can effectively make a rough estimate of the starting position of the receiving frame (candidates for the sample starting point). This is another effect of the present invention.

Also, according to the present invention, the constitution is such that it has a soft judgment phase error correction function by means of MMSE in the conventional decoding processing ("sum-product algorithm"). As a result, for example, it is possible to obtain a receiver for which degradation in the characteristics (decoding performance) can be suppressed even when a timing offset about 40° takes place. This is another effect of the present invention.

Then, according to the present invention, a frame constitution without a preamble or user code is used with which frame synchronization control and decoding processing can be performed while the timing offset and frequency offset are corrected, without using a PLL. As a result, it is possible to prevent wasteful redundancy of the frame, and it can provide a receiver that allows correct detection of the frame position. This is another effect of the present invention.

Then, according to the present invention, the constitution is such that the 2M+1 candidates for the sample starting point are determined using the carrier sense function. With said carrier sense function, it is possible to obtain a receiver that can effectively make a rough

determination of the starting position of the receiving frame (candidates for the sample starting point). This is another effect of the present invention.

Also, according to the present invention, the constitution is such that it has a soft judgment phase error correction function by means of MMSE in the conventional decoding processing ("sum-product algorithm"). As a result, for example, it is possible to obtain good characteristics (decoding performance) even when a timing offset of about 40° takes place. This is another effect of the present invention.

Then, according to the present invention, a frame constitution without a preamble or user code is used with which frame synchronization control and decoding processing can be performed while the timing offset and frequency offset are corrected, without using a PLL. As a result, it is possible to prevent wasteful redundancy of the frame, and it can make correct detection of the frame position. This is another effect of the present invention.

Then, according to the present invention, the constitution is such that the 2M+1 candidates for the sample starting point are determined using the carrier sense function. With said carrier sense function, it is possible to make a rough determination of the starting position of the receiving frame (candidates for the sample starting point). This is another effect of the present invention.

Industrial application field

As explained above, the communication system, receiver and communication method of the present invention are useful in systems to performing synchronization control without using preamble, user code, or other specific symbols. In particular, they are effective for use in a communication systems that perform synchronization control using LDPC encoded signals.

Claims

1. A communication system characterized by the fact that it is comprised of the following parts:

a transmitter that executes the LDPC (Low-density Parity-check) encoding process,

a decoding means that executes LDPC decoding once (iteration: 1) with "sum-product algorithm" with respect to the received signal at plural sample points as candidates for the sample starting point, a phase error estimating means that uses the soft judgment information output during the process of said decoding to execute phase error estimation using minimum mean square error method (MMSE), and a correcting means that corrects the received signal on the basis of said estimation result.

2. The communication system described in Claim 1 characterized by the fact that said receiver determines the candidates for the sample starting point by means of carrier sensing.

3. The communication system described in Claim 1 characterized by the following facts: said receiver also has

a frame synchronization control means that performs the following operation: judgment is made on whether said correction process is finished by comparing the mean value of the absolute values of the latest logarithmic likelihood ratios (A) with the mean value of the absolute values of the immediately preceding logarithmic likelihood ratios (B); if the judgment result is $B < A$, the received signal after correction is used to execute LDPC decoding and correction process again; on the other hand, if the result of execution of repeated decoding using the corrected received signal is $B \geq A$, the correction process is finished; then, the maximum value is selected from the mean values of the absolute values of the logarithmic likelihood ratios corresponding to the candidates for said sample starting point; and the point corresponding to the maximum value is taken as the sample starting point of the frame;

said decoding means repeats LDPC decoding until a prescribed number of iterations is reached or until there are no errors for the selected frame.

4. The communication system described in Claim 3 characterized by the fact that said receiver determines the candidates for the sample starting point by means of carrier sensing.

5. A receiver characterized by the fact that it has the following parts:

a decoding means that executes LDPC decoding once (iteration: 1) with "sum-product algorithm" with respect to the received signal at plural sample points as candidates for the sample starting point,

a phase error estimating means that uses the soft judgment information output during the process of said decoding to execute phase error estimation using the minimum mean square error method (MMSE),

and a correcting means that corrects the received signal on the basis of said estimation result.

6. The receiver described in Claim 5 characterized by the fact that it determines the candidates for the sample starting point by means of carrier sensing.

7. The receiver described in Claim 5 characterized by the following facts:

it also has a frame synchronization control means that performs the following operation: judgment is made on whether said correction process is finished by comparing the mean value of the absolute values of the latest logarithmic likelihood ratios (A) with the mean value of the absolute values of the immediately preceding logarithmic likelihood ratios (B); if the judgment result is $B < A$, the received signal after correction is used to execute LDPC decoding and correction process again; on the other hand, if the result of execution of repeated decoding using the corrected received signal is $B \geq A$, the correction process is finished; then, the maximum value is selected from the mean values of the absolute values of the logarithmic likelihood ratios

corresponding to the candidates for said sample starting point; and the point corresponding to the maximum value is taken as the sample starting point of the frame;

said decoding means repeats LDPC decoding until a prescribed number of iterations is reached or until there are no errors for the selected frame.

8. The receiver described in Claim 7 characterized by the fact that the candidates of the sample starting point are determined by means of carrier sensing.

9. A communication method characterized by the fact that it is comprised the following steps of operation:

a first decoding step in which LDPC (Low-density Parity-check) decoding is executed once (iteration: 1) with "sum-product algorithm" with respect to the received signal at a prescribed sample point,

a phase error estimating step in which the soft judgment information output during the process of said decoding is used to execute phase error estimation using the minimum mean square error (MMSE) method,

a first correction step in which the recorded signal is corrected on the basis of said estimation result,

a judgment step in which judgment is made on whether said correction process is finished by comparing the mean value of the absolute values of the latest logarithmic likelihood ratios (A) with the mean value of the absolute values of the immediately preceding logarithmic likelihood ratios (B),

a second correction step in which the operation is performed such that if the judgment result is $B < A$, the received signal after correction is used to execute LDPC decoding and correction process again;

a frame synchronization step in which the operation is performed such that on the other hand, if the result of execution of repeated decoding using the corrected received signal is $B \geq A$, the correction process is finished, the maximum value is selected from the mean values of the absolute values of the logarithmic likelihood ratios corresponding to the candidates for the sample starting point, and the point corresponding to the maximum value is taken as the sample starting point of the frame,

and a second decoding step in which said LDPC decoding is executed repeatedly until a prescribed number of iterations is reached or until there are no errors.

10. The communication method described in Claim 9 characterized by the fact that the candidates for the sample starting point are determined by means of carrier sensing.

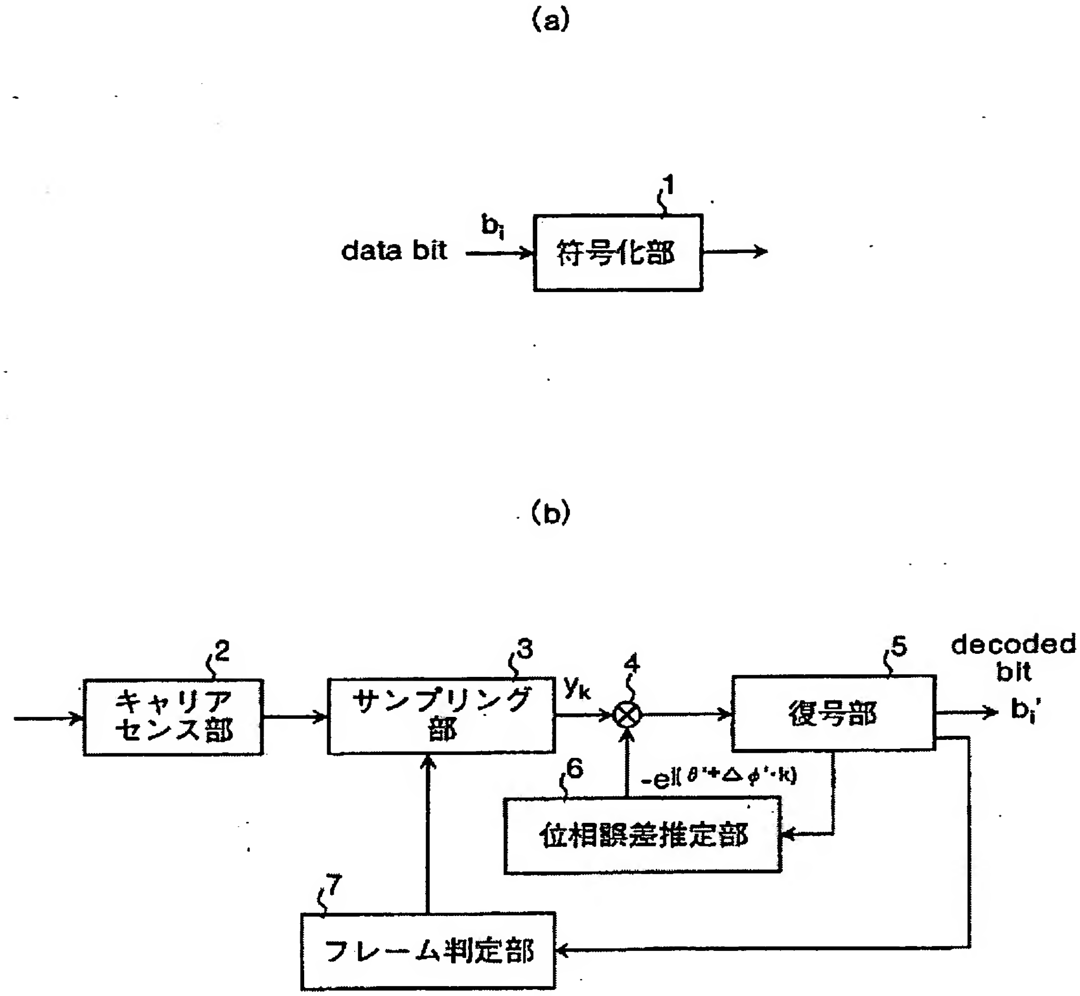


Figure 1

Key:
1 Encoding part
2 Carrier sense part
3 Sampling part
5 Decoding part
6 Phase error estimation part
7 Frame judgment part

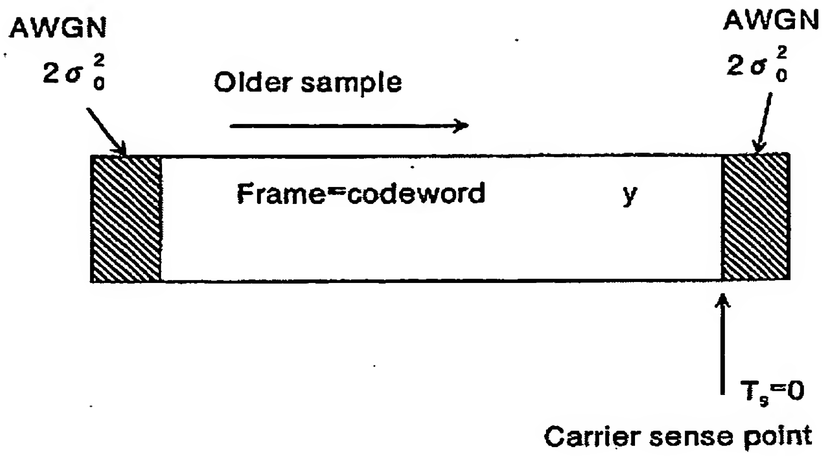


Figure 2

modulation	BPSK
Information length	3071
rate	0.5
channel	AWGN
Channel coding	LDPC code
Channel model	AWGN

Figure 3

rate	0.5		
codeword length	6140		
	x	λ_x	No.
	2	0.165506	2709
	3	0.187867	2050
	6	0.007331	40
	8	0.223851	916
	32	0.415445	425
	x	ρ_x	No.
	10	0.3125	1023
	11	0.6875	2046
σ_{GA}	0.959309		
SNR_{norm} (GA)	0.1719		

Figure 4

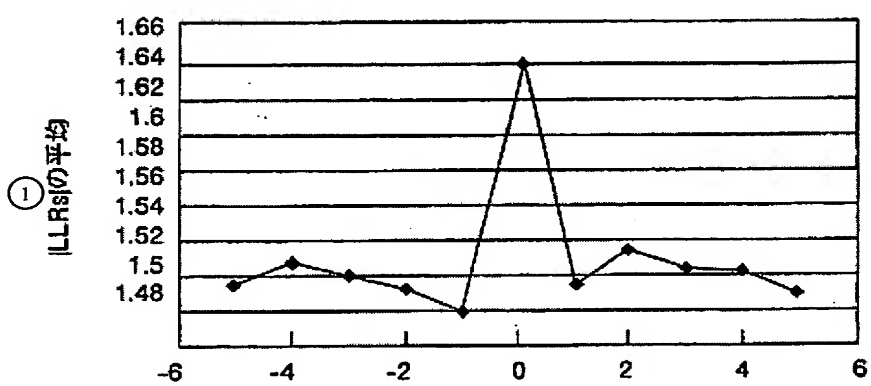


Figure 5

Key: 1 Mean value of ILLR

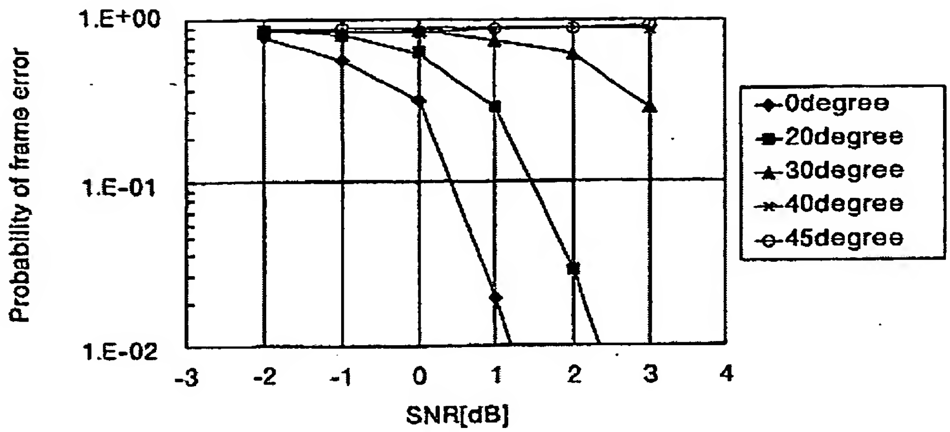


Figure 6

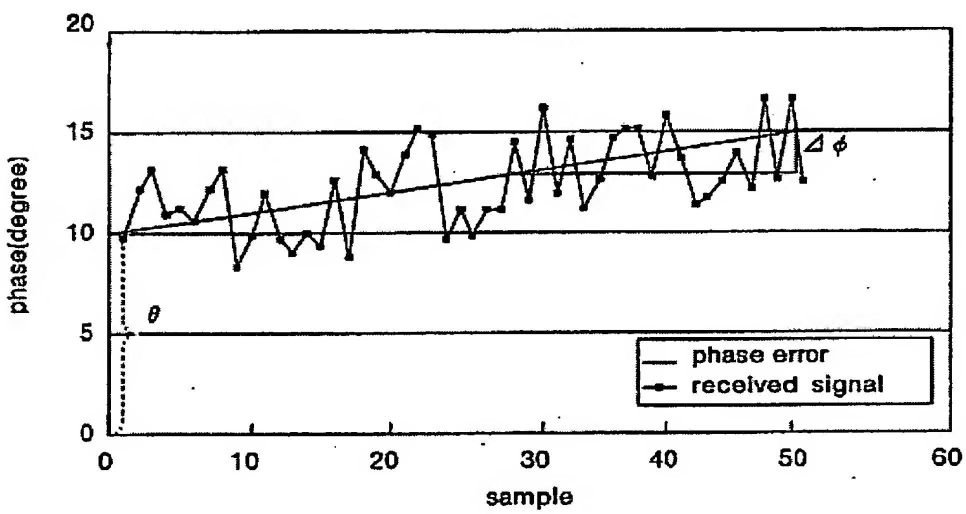


Figure 7

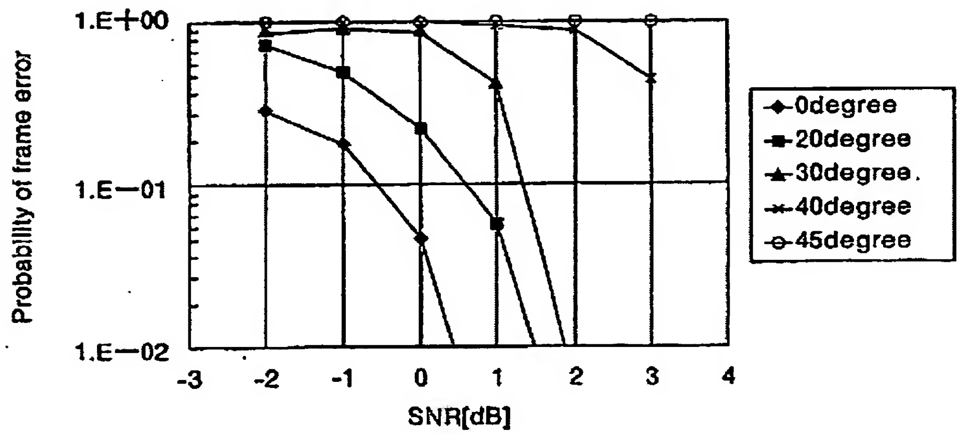


Figure 8

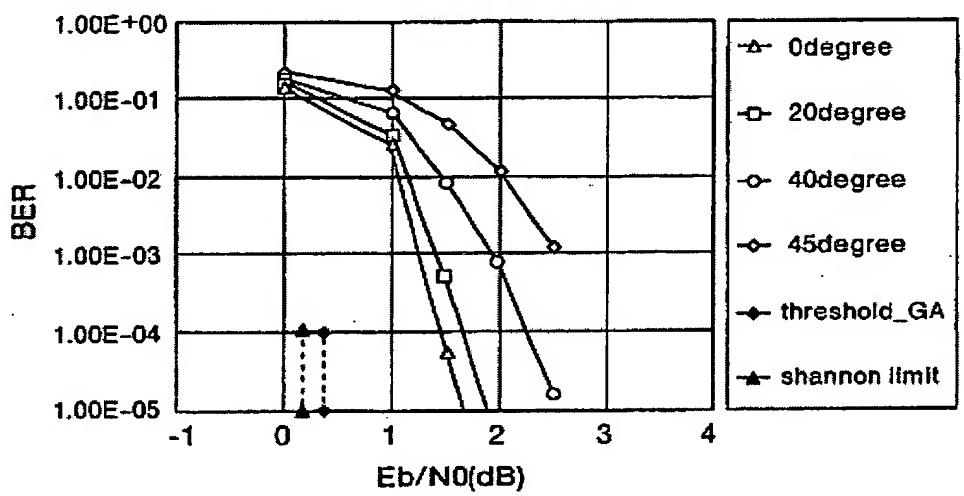


Figure 9

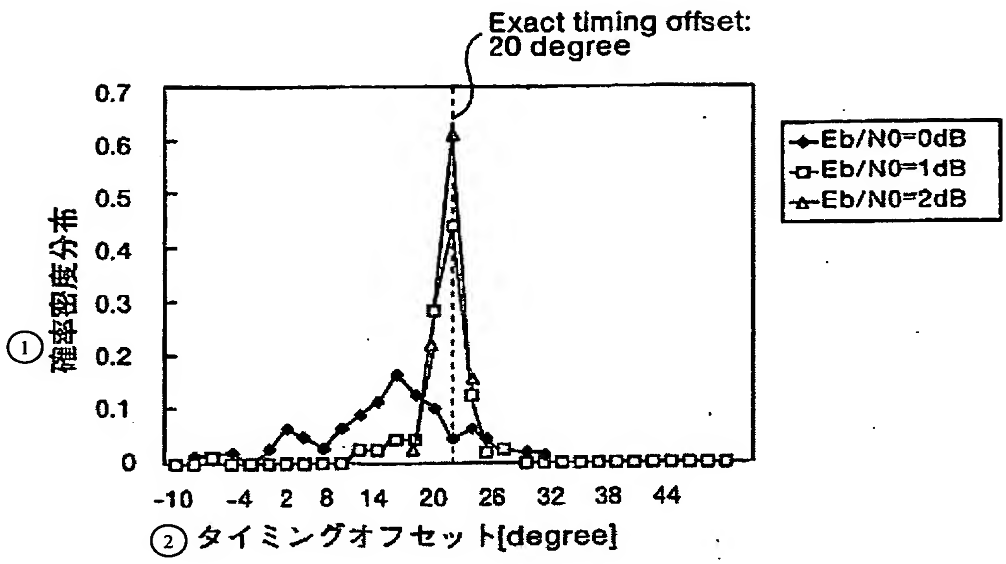


Figure 10

Key: 1 Probability density distribution
2 Timing offset (degree)

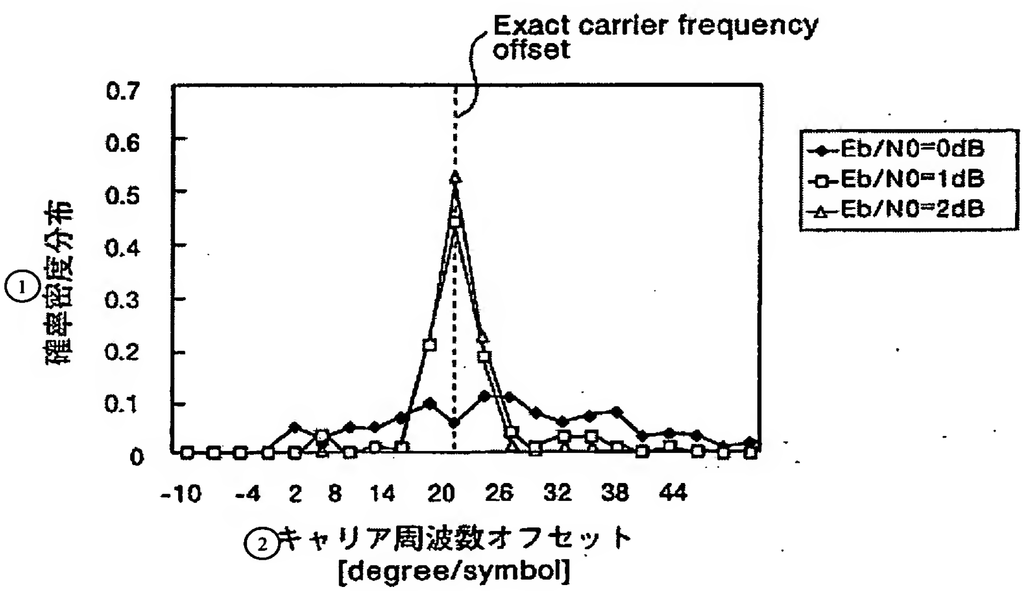


Figure 11

Key: 1 Probability density distribution
2 Carrier frequency offset (degree/symbol)

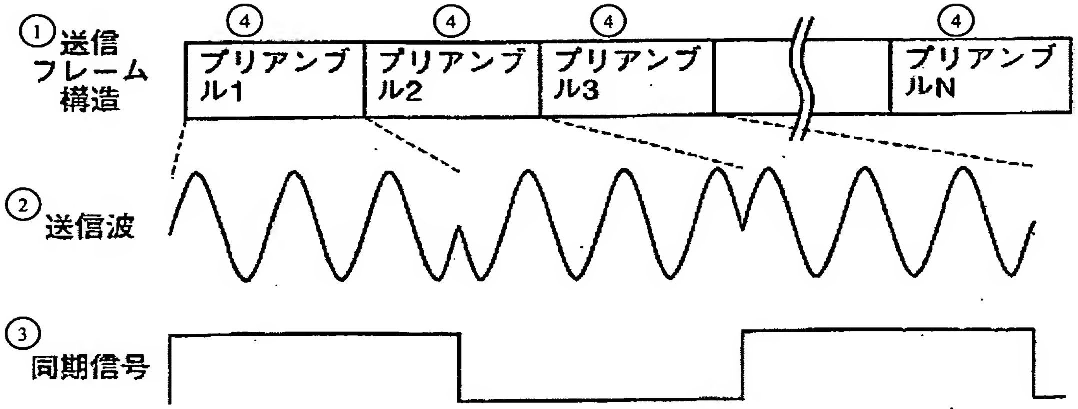


Figure 12

Key:
1 Transmitting frame structure
2 Preamble
3 Transmitted wave
4 Synchronization signal

Figure 13

Key:
1 Preamble N
2 User code
3 Control codes
4 Payload data

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP03/06396

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl^7 H04L7/08, H03M13/39

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl^7 H04L7/08, H03M13/39

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1926-1996	Jitsuyo Shinan Toroku Koho	1996-2003
Kokai Jitsuyo Shinan Koho	1971-2003	Toroku Jitsuyo Shinan Koho	1994-2003

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 10-150439 A (NTT Mobile Communications Network Inc.), 02 June, 1998 (02.06.98), Full text & EP 831616 A2 & US 5953378 A	1-10
A	JP 8-125640 A (Murata Machinery Ltd.), 17 May, 1996 (17.05.96), & US 5852639 A	1-10
A	JP 2001-168733 A (Thomson-CSF), 22 June, 2001 (22.06.01), Column 2, lines 16 to 46 & EP 1093231 A1 & CA 2322983 A1	1-10

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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- "&" document member of the same patent family

Date of the actual completion of the international search 15 August, 2003 (15.08.03)	Date of mailing of the international search report 26 August, 2003 (26.08.03)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP03/06396

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,A	JP 2002-314520 A (Matsushita Electric Industrial Co., Ltd.), 25 October, 2002 (25.10.02), Full text & WO 02/87141 A1 & EP 1292063 A1	1-10
P,A	JP 2003-115768 A (International Business Machines Corp.), 18 April, 2003 (18.04.03), Full text (Family: none)	1-10
E,A	JP 2003-198383 A (Mitsubishi Electric Corp.), 11 July, 2003 (11.07.03), Full text (Family: none)	1-10